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(54) **Title:** OLIGOMERIC KETONE COMPOUNDS

(57) **Abstract:** A novel keto8enic compound is provided having general: Formula $R(OCH(CH_3)CH_2C(O))_n$-O-A wherein n is an integer of 3 to 10, A is the residue of a 3-keto alkan-1-o1 and R is selected from the group consisting of H, C1-C6 alkyl and acetoaeetyl- Prefered compounds are those wherein A is a residue is of 4-hydroxy-2 butanone. A particularly preferred compound is a 4-hydroxy-2-butanone ester of an R-3-hydroxybutyrate oligomer having general: Formula $H(OCH(CH_3)CH_2C(O))_n$-O-$CH_2$-CH2-(CO)-$CH_3$ Nutraceutical and pharmaceutical compositions are provided for use in treating one or more of acute trauma, hemorrhagic shock, neurodegeneration, diabetes, and epilepsy, stroke, head trauma, myocardial infarction, congestive heart failure, pulmonary failure, kidney failure, obesity depression, pain and impaired cognition.

# OLIGOMERIC KETONE COMPOUNDS

The present invention relates to novel oligomeric compounds which have utility as nutraceuticals and/or medicaments for producing ketosis in humans and animals for nutraceutical or therapeutic purposes.

It is known that ketone bodies, particularly (R)-3-hydroxybutyrate (D-β-hydroxybutyrate) and acetoacetate have both nutritional and therapeutic application in man and many animals. US 6,136,862 and US 6,232,345 (incorporated herein by reference) relate to the use of D-β-hydroxybutyrate, oligomers, esters and salts thereof, *inter alia*, in the treatment of cerebral edema and cerebral infarction. US 6,207,856 and PCT/US99/21015 also refer to β-hydroxybutyrate and its oligomers, esters and salts thereof in protecting against other forms of neurodegeneration *inter alia*, through their proposed ability to activate the TCA cycle and, through favorable redox reactions in cells and antioxidant activity, scavenge free radicals. β-hydroxybutyrate has also been demonstrated to have cardioprotectant effect and can increase cardiac efficiency (Sato et al, FASEB J, 9: 651-658, 1995).

US6,207,856, US6,136,862, US6,207,856 and PCT/US99/21015, incorporated herein by reference, teach that preferred ketogenic precursors for producing such ketosis are monohydric-, dihydric and trihydric alcoholic esters of (R)-3-hydroxybutyrate, but particularly a (R)-3-hydroxybutyryl ester of (R)-3-hydroxybutyrate, more preferably the diester formed from two molecules of (R)-3-hydroxybutyrate and one molecule of (R)-1, 3-butandiol.

However, it is also known that production of oligomers of (R)-3-hydroxybutyrate in pure form is problematic. PCT/US99/21015 exemplifies a ketogenic oligomer with a mixture of (R)-3-hydroxybutyrate trimer, tetramer and pentamer and exemplifies esters thereof with acetoacetyl trimer, tetramer and pentamer of (R)-3-hydroxybutyrate. Similarly, Hiraide et al (1999) *J. Parenteral and Enteral Nutrition* Vol 23. No 6, discloses use of a mixture of dimer and trimer of (R)-

3-hydroxybutyrate for studies on the ability of plasma to degrade these to the monomer.

In order to ensure a previously untested material is safe and appropriate for human administration by any route, it is necessary to evaluate all of its significant components for toxicity and efficacy. In case of multicomponent materials it is thus necessary to test each one of these in a variety of toxicology and efficacy tests. Such tasks can be extremely expensive and time consuming and inevitably is an important factor in any decision of whether or not to proceed with any particular assessment. Furthermore, a mixture of different components may need to be produced in a set ratio for its safety and efficacy evaluation to be valid.

The present invention provides a single component oligomeric ketogenic material which is suitable for use in animals and man for therapeutic purposes.

In a first aspect of the present invention there is provided a compound of general formula

$$R(OCH(CH_3)CH_2C(O))_n\text{-}O\text{-}A$$

wherein n is an integer of 3 to 10, A is the residue of a 3-keto alkan-1-ol and R is selected from the group consisting of H, $C_1$-$C_6$ alkyl and acetoacetyl-

Preferably A is the residue is of 4-hydroxy-2-butanone and the compound is a 4-hydroxy-2-butanone ester of an (R)-3-hydroxybutyrate oligomer having general formula

$$H(OCH(CH_3)CH_2C(O))_n\text{-}O\text{-}CH_2\text{-}CH_2\text{-}(CO)\text{-}CH_3$$

More preferably n is 3 to 5, still more preferably being 3.

In a second aspect of the present invention there is provided a nutraceutical or pharmaceutical composition comprising a compound of the first aspect together with a foodstuff or beverage component or a pharmaceutically acceptable carrier, diluent or excipient. Suitable foodstuff and beverage components may include, but are not limited to, edible oils, liquids, emulsions, gels and solids.

In a third aspect of the present invention there is provided the use of a compound of the first aspect of the present invention for the manufacture of a

medicament for producing a physiologically acceptable ketosis. Such medicament will be suitable for treating, *inter alia,* diseases and medical conditions that are responsive to a bioavailable ketogenic agent, which include, but are not limited to, acute trauma, hemorrhagic shock, neurodegeneration, diabetes, and epilepsy, stroke, head trauma, myocardial infarction, congestive heart failure, pulmonary failure, kidney failure, obesity depression, pain and impaired cognition

In a fourth aspect of the present invention there is provided a method for a the manufacture of a compound of the first aspect comprising reacting a cyclic oligomer of (R)-3-hydroxybutyrate containing between 3 and 10 (R)-3-hydroxybutyrate moieties with a 3-keto alkan-1-ol in an organic solvent in the presence of a lipase.

Preferably the solvent is a furan or pyran. The lipase may be selected from any commercially available lipase, but specifically may be selected from *Candida antarctica* lipase-type B (CAL-B or Novozym®435), *Pseudomonas cepecia* (PS; Amano Pharmaceuticals) and *Mucor meihei* lipase. Novozyme® 435 is available from Novozymes, Denmark.

Still more preferably the method is that wherein n is 3, A is a 4-hydoxy-2-butanone residue, R is H, the cyclic oligomer is (R)-3-hydroxybutyrate triolide, the alcohol is 4-hydroxy-2-butanone, the solvent is tetrahydrofuran (THF) and the lipase is, particularly that available from Novozyme as Novozym®435 (CAL-B).

By the term 'residue' as used in respect of A is intended the moiety remaining after the alcohol is esterified with the oligomer, ie. not including the alcoholic oxygen; thus the residue of 4-hydroxy-2-butanone is the group $CH_3$-(CO)-$CH_2$-CH2-, with the residue being connected to the rest of the molecule directly through its 4-carbon.

Compounds where R is $C_1$-$C_6$ alkyl and acetoacetyl can be made from the corresponding compound where R is H by simple esterification with the acetoacetate or an alkylating agent.

The present invention is advantageous over the copending application method using (R)-1,3-butandiol esters in so far as ketones such as butanone are: (i) miscible in

non-polar organic media, (ii) has a small substituent in the β-position to the primary hydroxyl group, (iii) is equivalent to an oxidized form of 1,3-butandiol, (iv) is achiral, (v) only yields one ester product thus simplifying purification and (vi) can use a number of known commercially available lipases.

Regarding starting materials for producing the compounds of the present invention, various cyclic esters of (R)-3-hydroxybutyrate are known in the art and are readily produced by known methods: see for example Seebach et al. Helvetia Chimica Acta Vol 71 (1988) pages 155-167, and Seebach et al. Helvetia Chimica Acta, Vol 77 (1994) pages 2007 to 2033 incorporated herein by reference.

The present invention will now be described further by reference to the following non-limiting Examples, Schemes and Figures. Further embodiments falling within the scope of the claim will occur to those skilled in the art in the light of these.

**FIGURES**

Figure 1: The synthesis of (R,R,R)-4,8,12-trimethyl-1,5,9-trioxadodeca-2,6,10-trione [(R)-3-hydroxybutyrate triolide]

Figure 2: The reaction scheme for synthesis of a 2-keto-butan-4-ol-derived compound of the invention with a further reaction shown for converting this molecule to the (R)-3-hydroxybutyrate analogue thereof.

Figure 3: Ketogenic effect of oral administration of the reference standard, KTX 0101 (sodium (R)-3-hydroxybutyrate), as determined by increases of β-hydroxybutyrate concentrations in rat plasma.

Figure 4: Ketogenic effect of oral administration KTX 0204 (2-keto-butan- 4-ol ester) as determined by increases of β-hydroxybutyrate concentrations in rat plasma

EXAMPLES

__General procedure for the synthesis of R-3HB triolide from poly(3-hydroxybutyrate), PHB (Fig 1).__

A mixture of PHB (36g) and toluene-4-sulphonic acid monohydrate (23g) in 750 ml of toluene/dichloroethane (4:1) was heated and stirred at reflux at 120°C for 20 hrs. The water was removed azeotropically using a Dean-Stark trap for 15 hrs. The resulting clear brown solution was cooled to room temperature, washed with a half-saturated solution of $Na_2CO_3$, then washed with a saturated solution of NaCl, dried over $MgSO_4$, filtered and evaporated to dryness. The crude mixture was purified by column chromatography using silica gel as the stationary phase and an 8% hexane/ethylacetate mixture as the eluent followed by repeated crystallizations in hexane/ethylacetate. The yield of the purified product was 15g (40%). Analysis of the product was as follows: melting point 110°C; $^1H$ NMR (300 MHz, $CDCl_3$ ): δ 1.30 (d, J=6.4 Hz, $CH_3$), 2.39 (dd, J=2.1, 11.3 Hz), 2.46 (dd, J=11.3, 13.5Hz) and 5.31-5.39 (m, CH); $^{13}C$ NMR (75.5 MHz, $CDCl_3$ ): δ 20.76 ($CH_3$), 42.16 ($CH_2$), 68.87 (CH) and 170.01 (CO).

## EXAMPLE 1

__Synthesis of KTX 0204 (2-keto-butan-4-ol ester) via the lipase-catalyzed ring opening of (R)-3-hydroxybutyrate triolide using 4-hydroxy-2-butanone as the acyl acceptor (Fig. 2)__

The lipase-catalyzed ring-opening of (R)-3HB triolide using 2-keto-4-butanol (4-hydroxy-2-butanone) as the acyl acceptor was found to occur when performed in THF at 48°C or 55°C. Although a number of lipases were found to be active for this transformation (Table 1), our work focused on the use of CAL-B. With CAL-B, the reaction was performed in THF for 72 hrs at 40°C.

Purified triolide (1g, 3.88mmol) was added into a round-bottom flask (50 ml) with 2-keto-4-butanol (683mg, 7.8mmol), anhydrous THF (20ml), and CAL-B

(536mg, 30%-by-wt relative to total substrates). The product was visualized on thin layer chromatography (tlc) plates by converting its terminal hydroxyl group to the corresponding acetate derivative. This derivatization was performed on the tlc plate by first heating the plate with acetic anhydride followed by charring with CAM. The product was purified by column chromatography. The column was packed in pure chloroform and was eluted with methanol : chloroform, 1:49).

The product was a water-soluble syrup and the yield was 65%.

*$^1H$ NMR ($CDCl_3$):* δ 1.20-1.31 (9H, m,J= 6.4Hz, $CH_3$), 2.19 (3H,s,$CH_3$), 2.41-2.81 (6H,m,CO$CH_2$×3), 3.30 (1H,s,OH), 3.82-3.86 (1H,m,CH), 4.16-4.21 (1H,m,$COCH_b$) and 4.31-4.38 (3H,m,CH,$COCH_a$) and 5.30-5.26 (1H,m,CH).

*$^{13}C$ NMR ($CDCl_3$):* δ 19.89, 22.47, 30.23 ($CH_3$), 59.39 (C-4), 43.28 (C-3), 42.84 (C-14), 42.09 (C-10), 40.66(C-6), 64.33(C-15), 67.57 (C-7,C-11) , 172.03, 172.59 (CO) and 205.60 (CO).

*CHN Analysis:* Anal. Calcd for $C_{16}H_{26}O_8$: C, 55.48; H, 7.57; O, 36.95. Found: C, 55.02; H,7.79; O, 37.19.

**EXAMPLE 2**

**The use of various commercial lipases to catalyse the synthesis of KTX 0204 (2-keto-butan-4-ol ester) via the lipase-catalyzed ring opening of (R)-3-hydroxybutyrate triolide using 4-hydroxy-2-butanone as the acyl acceptor**

4-Hydroxy-2-butanone was reacted with (R)-3-hydroxybutyrate triolide under a number of different conditions (Table 1). 4-Hydroxy-2-butanone is a small and active acyl acceptor using a wide range of lipases, including *Candida antarctica* lipase (CAL-B or Novozyme 435), *Pseudomonas cepecia* lipase (Amano Pharmaceuticals) and *Mucor meihei* lipase. The reactions between 4-hydroxyl-2-butanone and (R)-3-hydroxybutyrate triolide with the lipases, apart from CAL-B, were performed in tetrahydrofuran using a 48 hr incubation period at temperatures

of both 40°C and 55°C. The incubation time with CAL-B was 72 hrs at 40°C and 55°C.

**Table 1: Experimental variables and results for the ring-opening of (R)-3-hydroxybutyrate triolide by reaction with 4-hydroxyl-2-butanone using a lipase as the catalyst.**

| Source of lipase enzyme | Solvent | Temperatures investigated (°C) | Result |
|---|---|---|---|
| *Candida antarctica* lipase (CAL-B) (Novozym 435) | Tetrahydofuran (THF) | 40 and 55 | Positive reaction |
| CAL-B on Accurel® support | THF | 40 and 55 | Positive reaction |
| *Pseudomonas cepecia* (PS.Amano) | THF | 40 and 55 | Positive reaction |
| *Mucor meihei* | THF | 40 and 55 | Positive reaction |

The reactions were conducted for 72 hrs for CAL-B and 48 hrs for the other lipases.

**EXAMPLE 3**

**Ketogenic effect of KTX 0204 (2-keto-butan- 4-ol ester )**

Male Sprague-Dawley rats (weight range 200-250g) were obtained from Charles River, Margate, Kent. The rats were group housed in polypropylene cages at

a temperature of 21±4°C and 55±20% humidity and on a standard light/dark cycle. Animals had free access to a standard pelleted rat diet and tap water at all times. Animals were accustomed to these conditions for at least one week before experimentation.

KTX 0204 (2-keto butan-4-ol ester), which was mostly soluble in deionized water and produced a cloudy and stable solution, was administered by gavage at 300mg/kg po. Control animals received the appropriate vehicle (deionized water at 1ml/kg) via the same route. Data for KTX 0101 (sodium (R)-3-hydroxybutyrate) are shown for comparison.

Animals were killed by $CO_2$ and blood (approx 5ml) was collected by cardiac puncture at various times after dosing. Blood was collected into EDTA-coated plasma collection tubes (Sarstedt 5 ml K2E tubes) and kept on ice prior to centrifugation. Tubes were centrifuged in an Eppendorf 570R centrifuge at 4°C for 5 minutes at 2500rpm (1000g). Following plasma separation, extreme care was taken to avoid contamination with red blood cells and samples were re-centrifuged as necessary. Plasma samples were initially frozen on dry ice and transferred to a -75°C freezer until required for analysis.

**Protocol for KTX 0204 only**

| Group | Number of animals | Time of blood sampling (min) | Treatment |
|---|---|---|---|
| A | 7 | 0 | Vehicle baseline |
| B | 4 | 30 | KTX 0204 (300mg/kg po) |
| C | 4 | 120 | KTX 0204 (300mg/kg po) |
| D | 4 | 240 | KTX 0204 (300mg/kg po) |

**Protocol for KTX 0101 only**

| Group | Number of animals | Time of blood sampling (min) | Treatment |
|---|---|---|---|
| A | 4 | 0 | Vehicle baseline |
| B | 4 | 15 | KTX 0101 (300mg/kg po) |
| C | 4 | 30 | KTX 0101 (300mg/kg po) |
| D | 4 | 120 | KTX 0101 (300mg/kg po) |

Sodium DL-β-hydroxybutyrate (H-6501 Lot 111K2618) was obtained from Sigma. A stock solution of β-hydroxybutyrate (40mM DL racemate equivalent to 20mM D-isomer) was prepared in 0.9% saline solution, kept at 4°C and used to generate appropriate dilutions for an assay standard curve. Such solutions have been shown to be stable for at least 2 months.

Commercial clinical assay kits for the determination of D-β-hydroxybutyrate were obtained from Randox Laboratories (Antrim, UK). Kits were obtained in two pack sizes (Ranbut-RB1007: 10x10ml and RB1008: 10x50ml) but were otherwise identical. Each kit contained a standard solution of 1mM D-β-hydroxybutyrate that was assayed every time to confirm the assay was performing correctly. The kit relies on measuring the appearance of NADH via the activity of β-hydroxybutyrate dehydrogenase measured as an increase of OD340nm. An alkaline pH is necessary to drive the reaction equilibrium towards the production of NADH and acetoacetate.

$$\text{Hydroxybutyrate} + \text{NAD}^+ \underset{\text{pH } 7.0}{\overset{\text{pH } 8.5}{\rightleftharpoons}} \text{NADH} + \text{Acetoacetate}$$

The protocol supplied with the Ranbut kits was for a discrete (cuvette-based) spectrophotometric assay, so the protocol was modified for suitability with a 96-well microplate format using blank, flat-bottomed microplates (Greiner PS 655101 Lot 98 35 01). Assays were performed in triplicate using a sample volume of 10µl to each

well for the standards and usually 20µl for plasma samples (though this was varied for some experiments). Standard dilutions and samples were pipetted a single plate at a time and preincubated at 37°C for 15 minutes in the sample compartment of a Molecular Devices VERSA$_{max}$ tunable microplate reader. The appropriate volume of assay reagent was reconstituted, according to instructions, using distilled water and preincubated at 37°C for 15 minutes using a static water bath. The assay plate was ejected and the reaction started by adding rapidly 250µl of reagent to each well (avoiding air bubbles). The plate was reloaded, mixed and then the change in OD340nm followed in kinetic mode with a reading at every 15 seconds for a total of 2 minutes. The reaction rate was then determined from the OD increase over a suitable 1 minute period, after allowing a necessary period for the reaction rate to settle. The rate between 45 seconds and 105 seconds was used as the default measuring period, though occasionally a different period was used as necessary (eg if an aberrant reading was obtained at one of these time-points).

For analysis of spectrophotometric rate assays, linear regression analysis to the standard curve was used followed by interpolation of unknown values (GraphPad Prism 3.0). For comparison of treatment groups with vehicle, multiple 2-tailed t-tests were used and $p<0.05$ was taken to indicate statistical significance.

**KTX 0101 (sodium (R)-3-hydroxybutyrate):** After oral administration at 300 mg/kg (po), the sodium salt of (R)-3-hydroxybutyrate rapidly increased plasma concentrations of β-hydroxybutyrate (Fig. 3). The maximum increase was 0.4mM observed at 15 min ($P<0.05$), it plateaued at this level until 30 min ($P<0.01$) and declined thereafter. The level β-hydroxybutyrate was still significantly ($P<0.05$) elevated at 1 h, but it returned to control values by 2 h.

**KTX 0204 (2-keto-butan- 4-ol ester ):** After oral administration at 300 mg/kg (po), the 2-keto-butan- 4-ol ester of (R)-3-hydroxybutyrate triolide rapidly increased plasma concentrations of β-hydroxybutyrate (Fig. 4). The maximum increase of

0.25mM observed at 30 min was not quite so large as that produced by the equivalent oral dose of sodium (R)-3-hydroxybutyrate, but the change was nevertheless highly significant ($P<0.01$). The plasma concentration of β-hydroxybutyrate declined thereafter and had returned to control values by 1 hr.

## CLAIMS

1. A compound of general formula

$$R(OCH(CH_3)CH_2C(O))_n\text{-}O\text{-}A$$

wherein n is an integer of 3 to 10, A is the residue of a 3-keto-alkan-1-ol and R is selected from the group consisting of H, $C_1$-$C_6$ alkyl and acetoacetyl-

2. A compound as claimed in Claim 1 wherein A is a residue is of 4-hydroxy-2-butanone.

3. A compound as claimed in Claim 1 which is a 4-hydroxy-2-butanone ester of an (R)-3-hydroxybutyrate oligomer having general formula

$$H(OCH(CH_3)CH_2C(O))_n\text{-}O\text{-}CH_2\text{-}CH_2\text{-}(CO)\text{-}CH_3$$

4. A compound as claimed in Claim 1 wherein n is an integer of 3 to 5.

5. A compound as claimed in Claim 1 wherein n is 3.

6. A nutraceutical or pharmaceutical composition comprising a compound as claimed in any one of Claims 1 to 6 together with a foodstuff or beverage component or a pharmaceutically acceptable carrier, diluent or excipient.

7. A nutraceutical composition as claimed in Claim 6 wherein the composition comprises a component of a beverage, which includes liquid, semi-solid or gelled preparations, or a component of a foodstuff, which also includes an edible oil, emulsion, gel or solid.

8. The use of a compound as Claimed in Claim 1 for the manufacture of a medicament for producing a physiologically acceptable ketosis.

9. Use as claimed in Claim 8 wherein the medicament is for the treatment of diseases and medical conditions that are responsive to physiologically acceptable ketosis.

10. Use as claimed in Claim 9 wherein the disease or medical condition is selected from acute trauma, hemorrhagic shock, neurodegeneration, diabetes, epilepsy, stroke, head trauma, myocardial infarction, congestive heart failure, pulmonary failure, kidney failure, obesity depression, pain and impaired cognition.

11. A method of treating a patient in need of therapy for one or more of acute trauma, hemorrhagic shock, neurodegeneration, diabetes, and epilepsy, stroke, head trauma, myocardial infarction, congestive heart failure, pulmonary failure, kidney failure, obesity depression, pain and impaired cognition comprising administering to the patient a therapeutically effective amount of a compound of Claim 1.

12. A method as claimed in Claim 11 wherein the amount of compound is sufficient to raise the patients' blood ketone levels to between 0.2 to 20mM.

13. A method for the manufacture of a compound of the first aspect comprising reacting a cyclic oligomer of (R)-3-hydroxybutyrate containing between 3 and 10 (R)-3-hydroxybutyrate moieties with a 3-keto-alkan-1-ol in an organic solvent in the presence of a lipase.

14. A method as claimed in Claim 13 wherein the solvent is a furan or pyran solvent.

15. A method as claimed in Claim 13 wherein lipase is selected from *Candida antarctica* lipase-type B (CAL-B or Novozym® 435), *Pseudomonas cepecia* (PS; Amano Pharmaceuticals) and *Mucor meihei* lipase.

16. A method as claimed in Claim 13 wherein n is 3, A is a 4-hydoxy-2-butanone residue, R is H, the cyclic oligomer is (R)-3-hydroxybutyrate triolide, the alcohol is 4-hydroxy-2-butanone, the solvent is tetrahydrofuran and the lipase is Novozym® 435 (CAL-B).

FIGURE 1

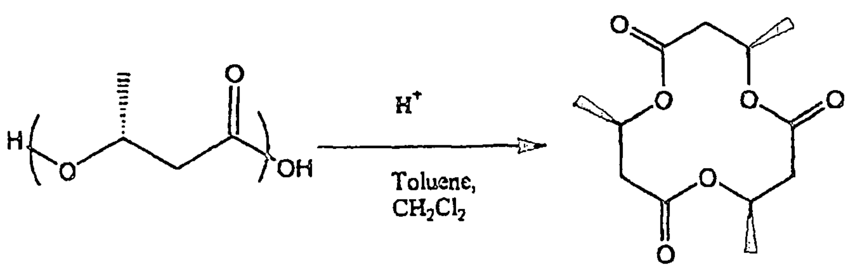


FIGURE 2

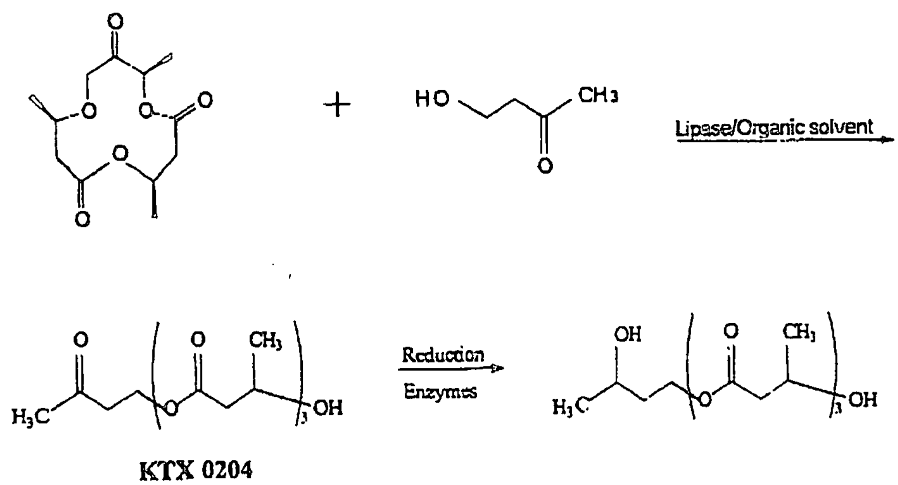
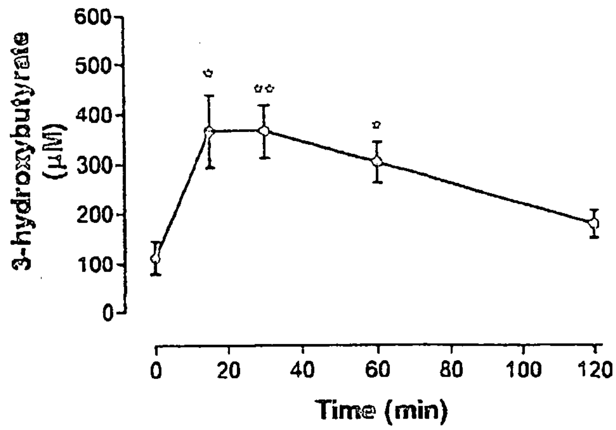

HO
CH3
Lipase/Organic solvent
O
CH3
OH
Reduction
Enzymes
H3C
3
KTX 0204

FIGURE 3



3-hydroxybutyrate (μM)
600
500
400
300
200
100
0
0
20
40
60
80
100
120
Time (min)

FIGURE 4